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Chen et al.

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(54) **FLUID TRANSPORTATION DEVICE HAVING MULTIPLE DOUBLE-CHAMBER ACTUATING STRUCTURES**

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F04B 43/06 (2006.01)
F04B 45/053 (2006.01)

(52) **U.S. Cl.** **417/533**; 417/413.1

(58) **Field of Classification Search** 417/413–413.3, 417/533, 566, 322, 395
See application file for complete search history.

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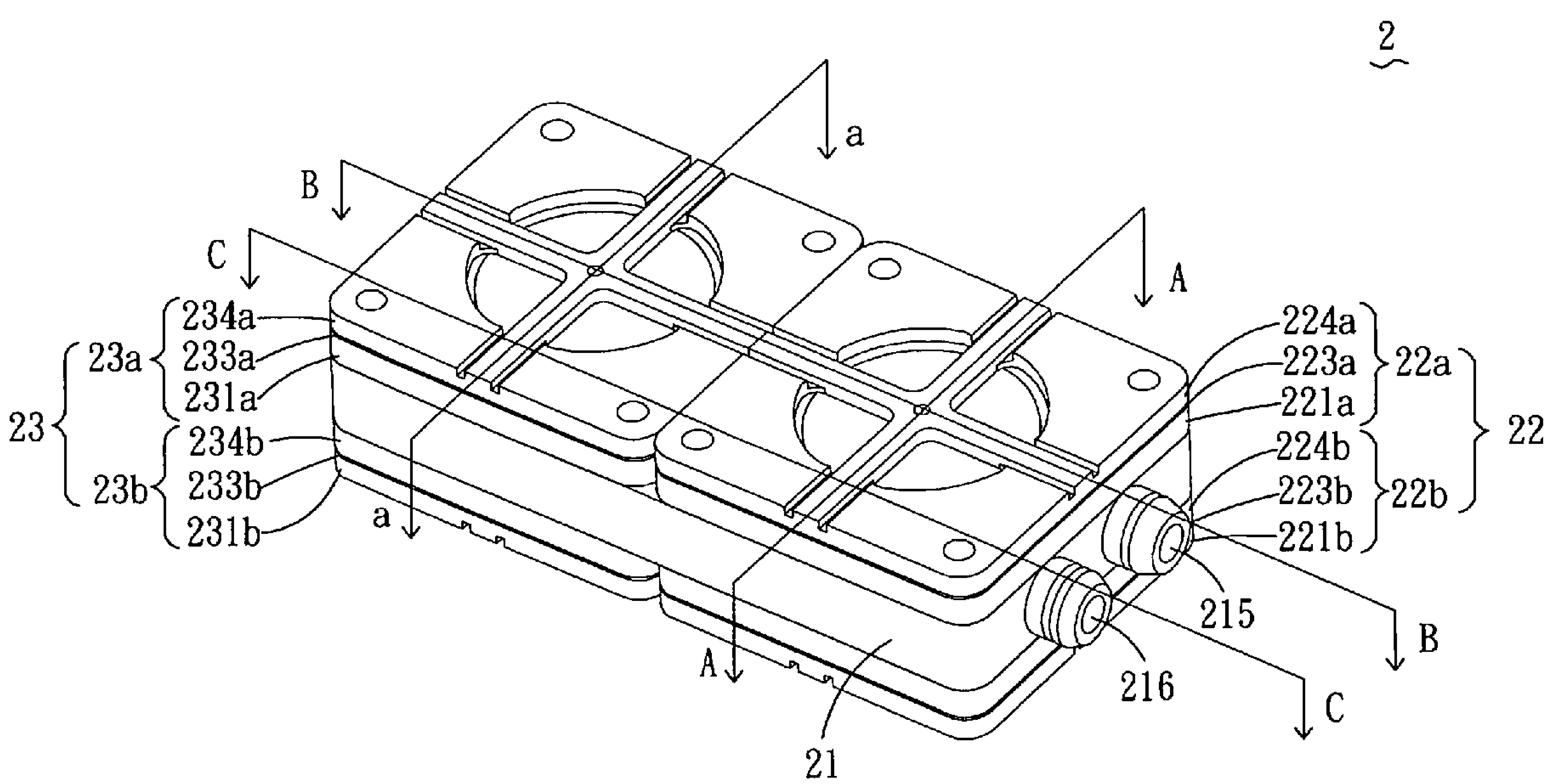
(57) **ABSTRACT**

A fluid transportation device includes a flow-gathering module and multiple double-chamber actuating structures. The flow-gathering module includes two surfaces opposed to each other, multiple first flow paths and multiple second flow paths running through the two surfaces, an inlet channel arranged between the two surfaces and communicated with the multiple first flow paths, and an outlet channel arranged between the two surfaces and communicated with the multiple second flow paths. The multiple double-chamber actuating structures are arranged on the flow-gathering module side by side. Each double-chamber actuating structure includes a first chamber and a second chamber symmetrically arranged on the two surface of the flow-gathering module. Each of the first chamber and the second chamber includes a valve cap arranged over the flow-gathering module, a valve membrane arranged between the flow-gathering module and the valve cap, and an actuating member having a periphery fixed on the valve cap.

9 Claims, 12 Drawing Sheets



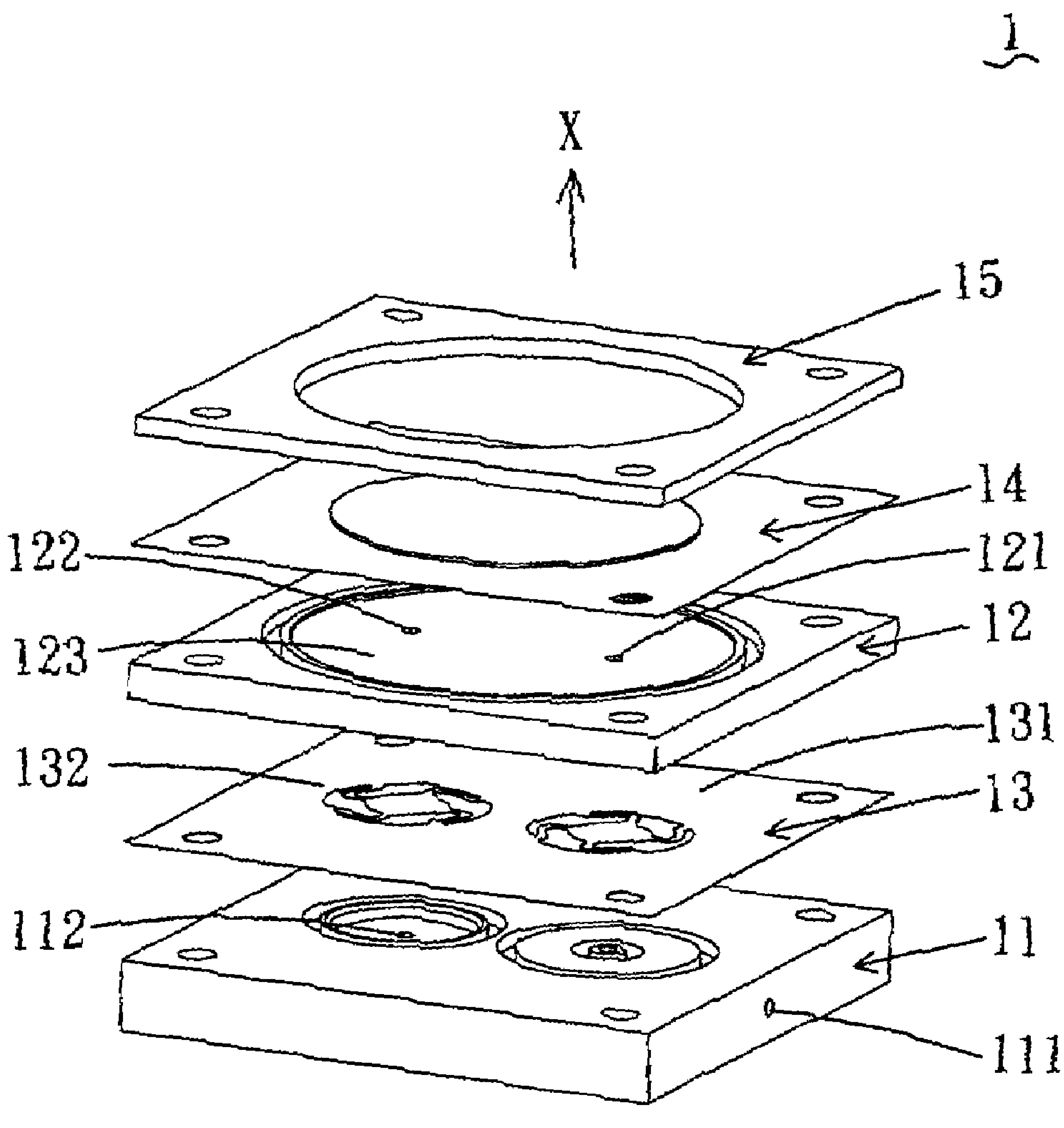
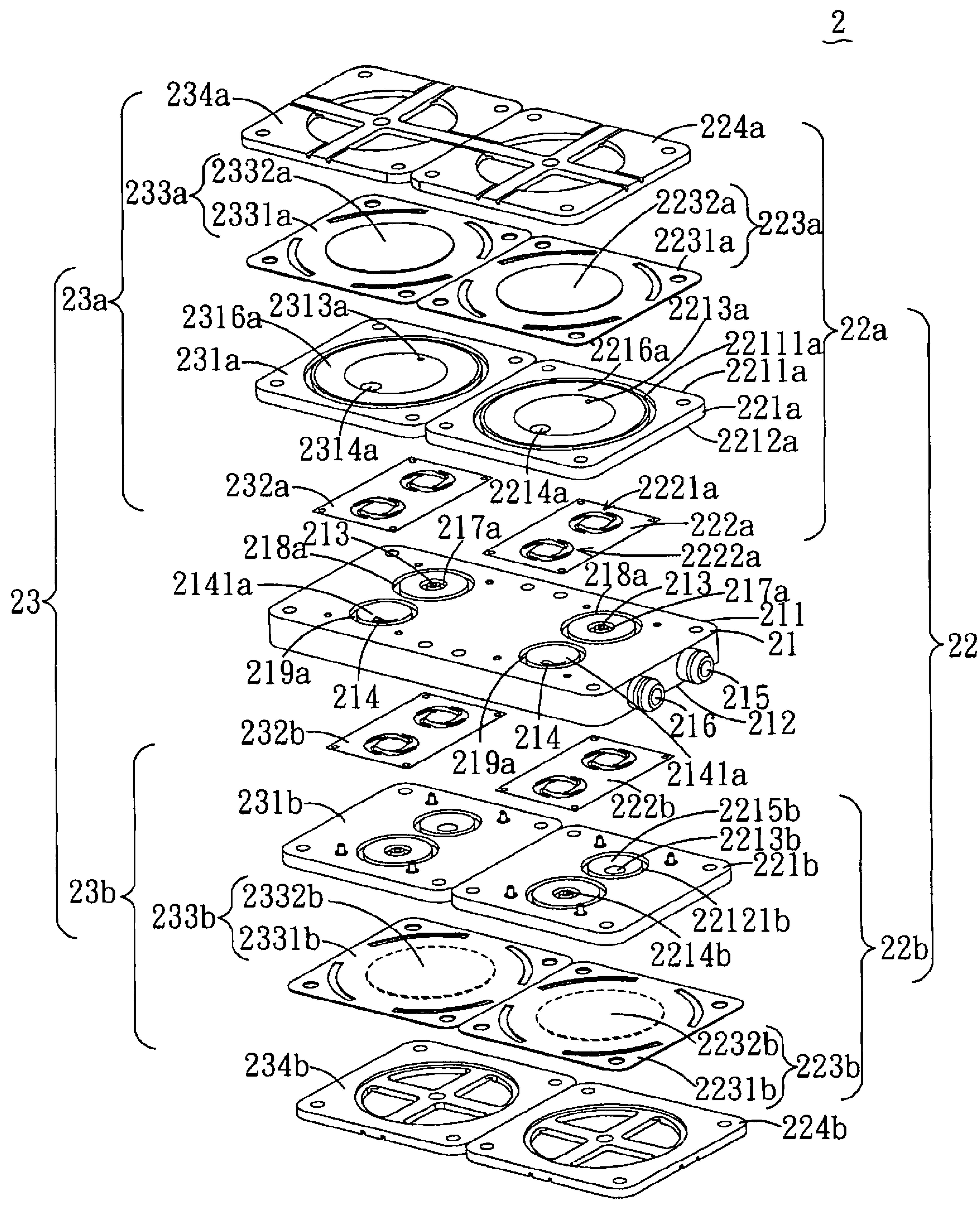


FIG. 1 (PRIOR ART)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233a
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2216a
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221a
2212a
2314a
2214a
232a
2221a
222a
2222a
218a
213
217a
2141a
218a
213
217a
211
21
23
22
219a
214
215
212
216
214
232b
219a
2141a
231b
222b
2215b
2213b
221b
23b
233b
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22121b
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22b
2232b
223b
234b
2231b
224b

FIG. 2

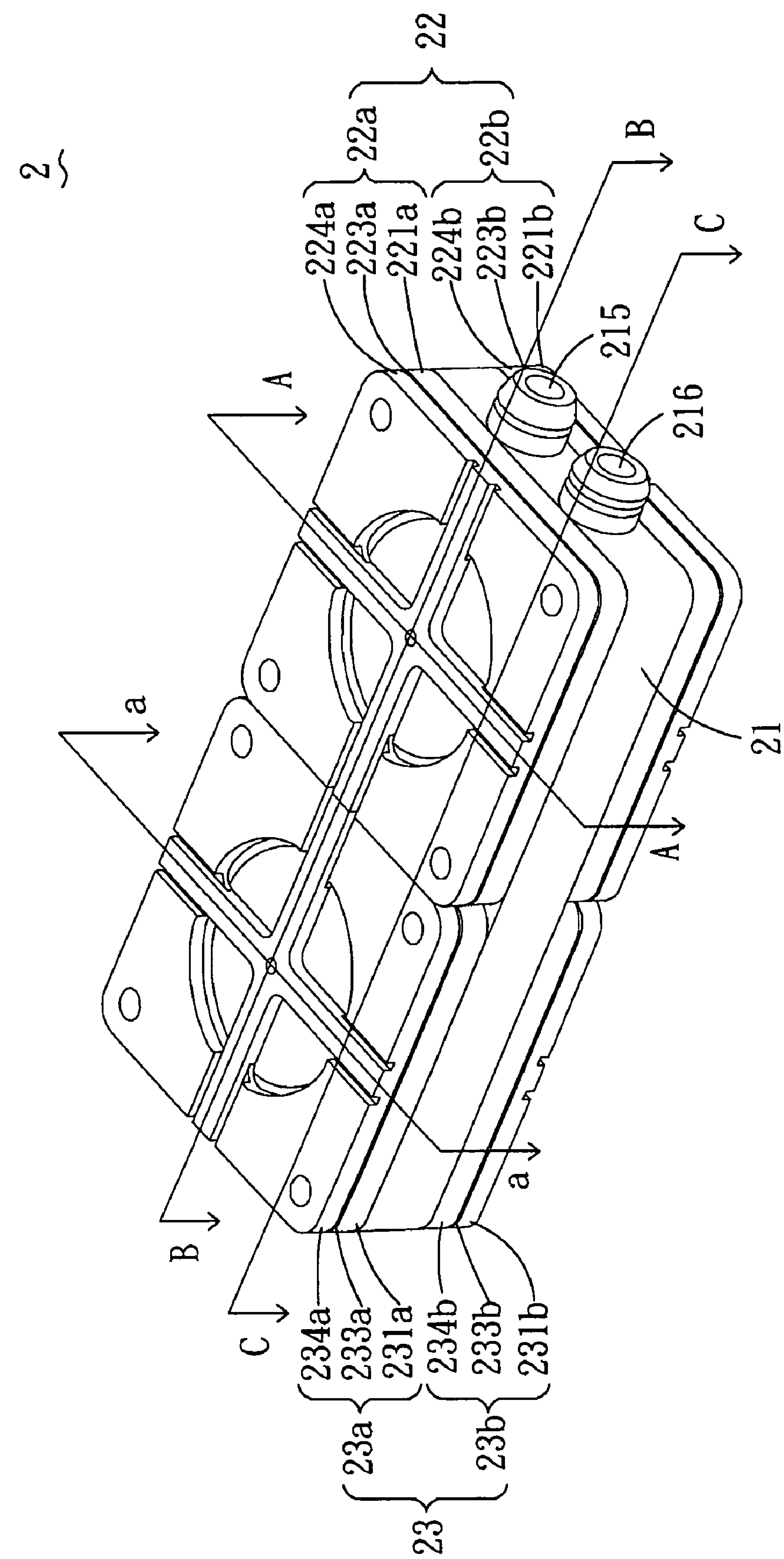
2
22
22a
22b
224a
223a
221a
224b
223b
221b
215
216
21
A
a
B
C
234a
233a
231a
234b
233b
231b
23a
23b
23

FIG. 3A

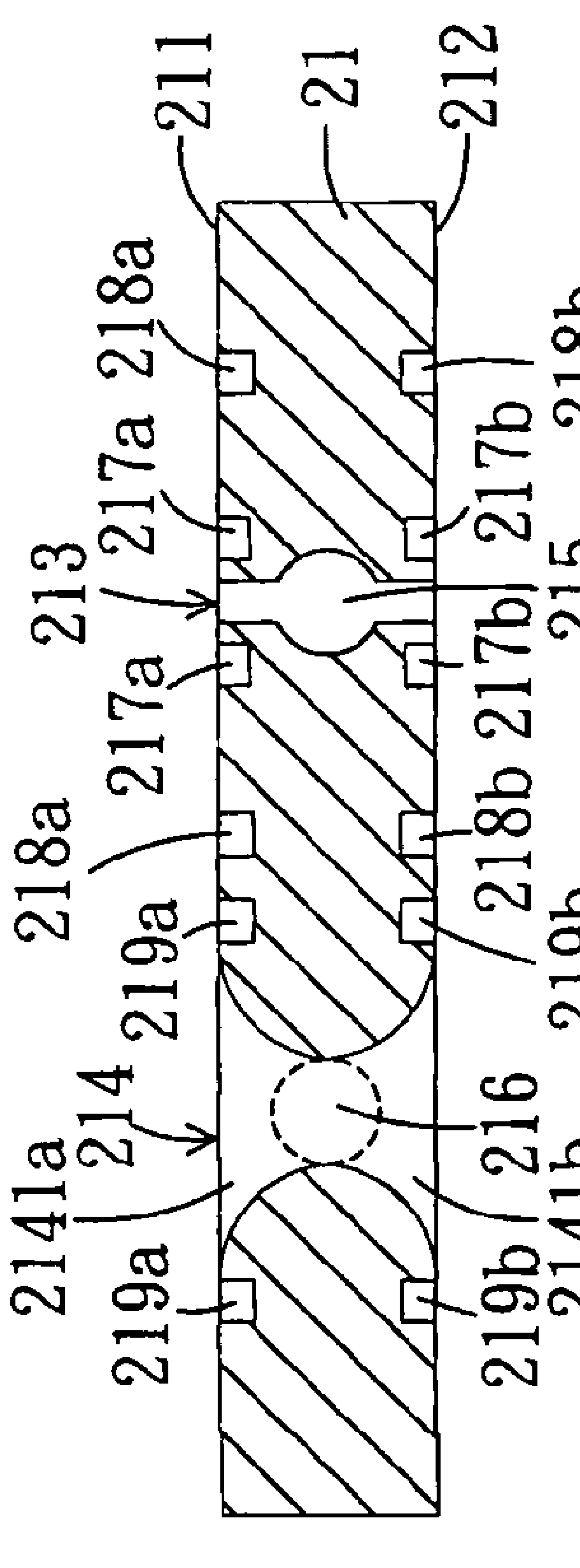

FIG. 3B

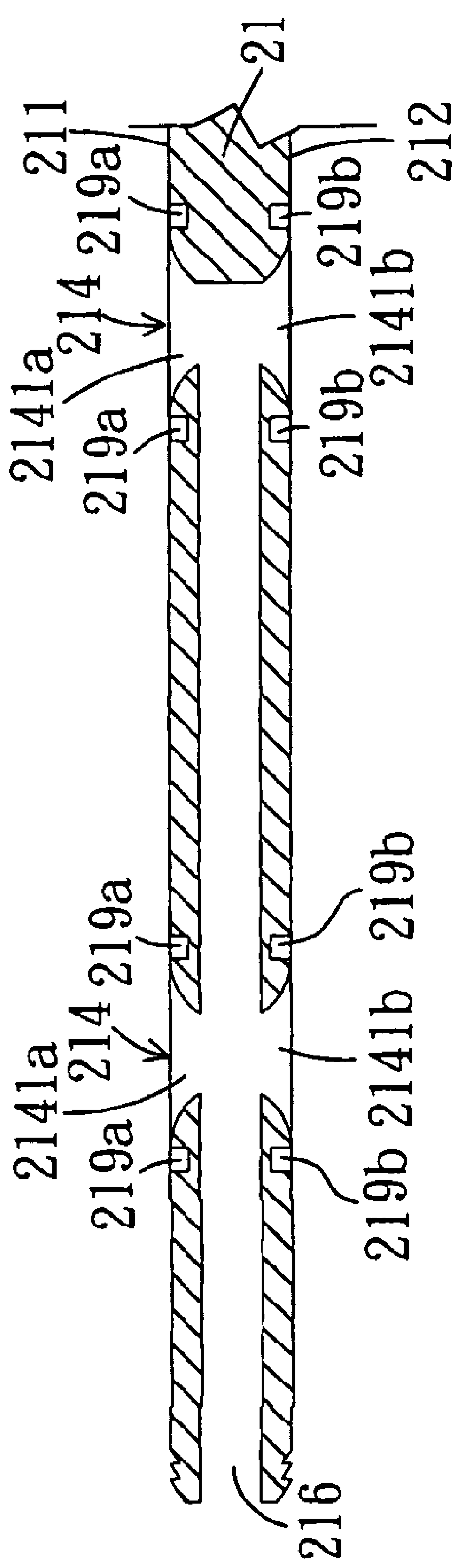

FIG. 3C

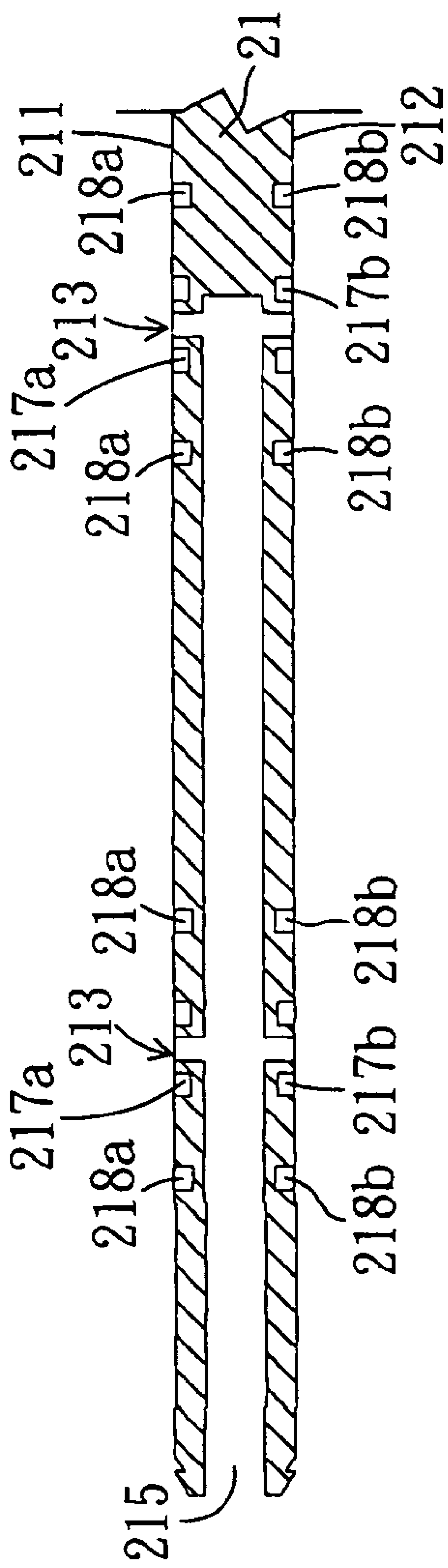

FIG. 3D

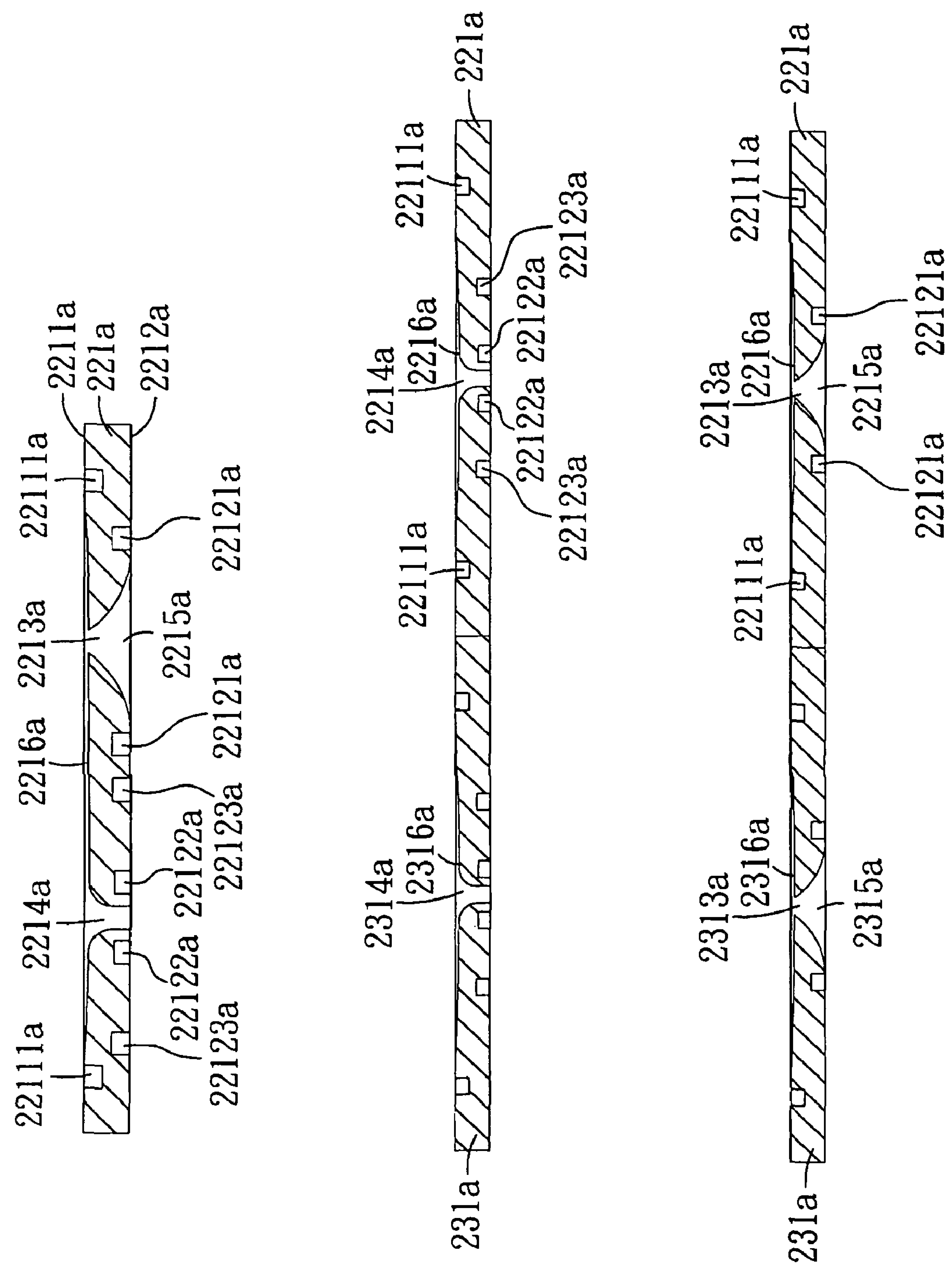

FIG. 4A

FIG. 4B

FIG. 4C

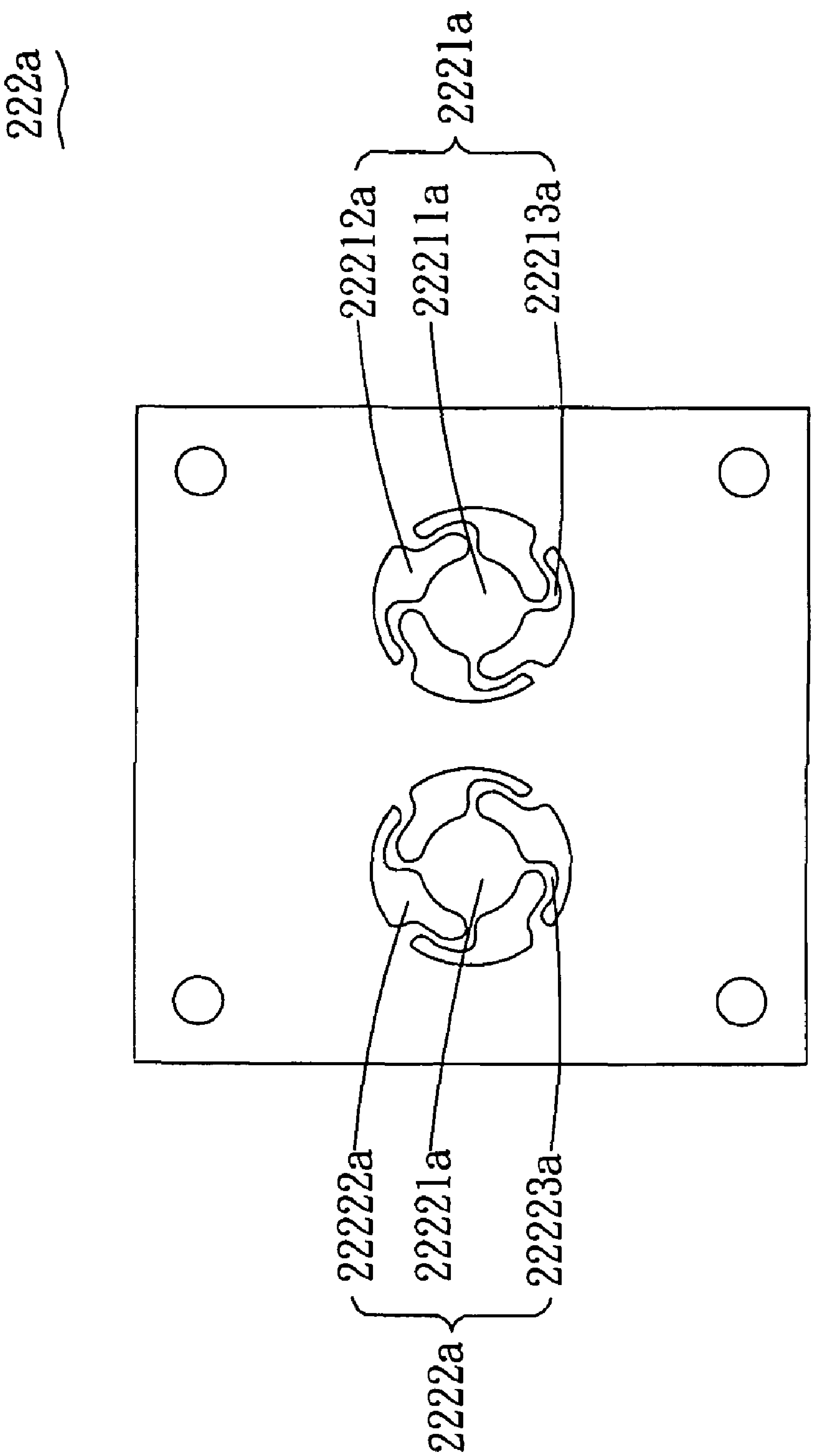
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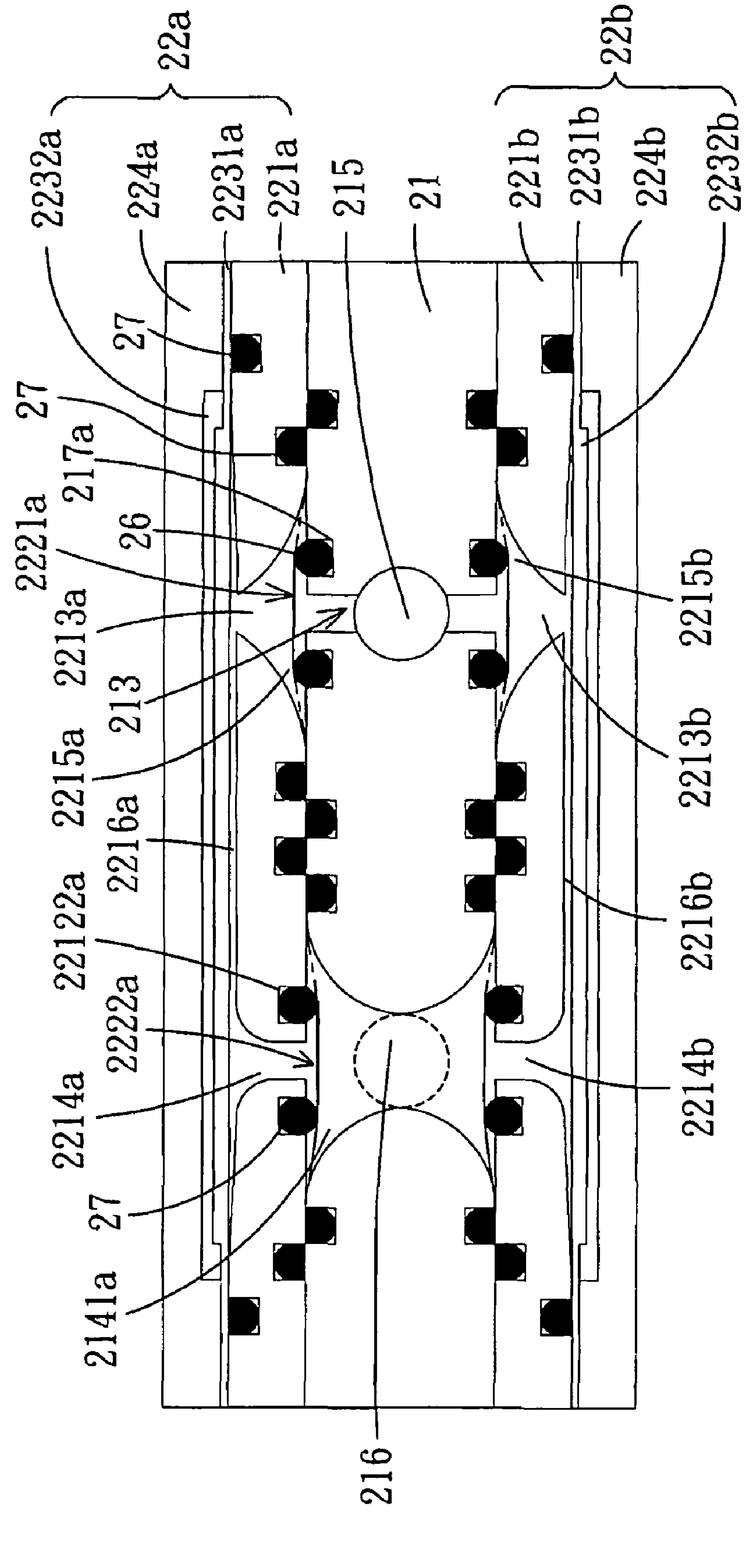
FIG. 5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215
21
221b
2231b
224b
2232b
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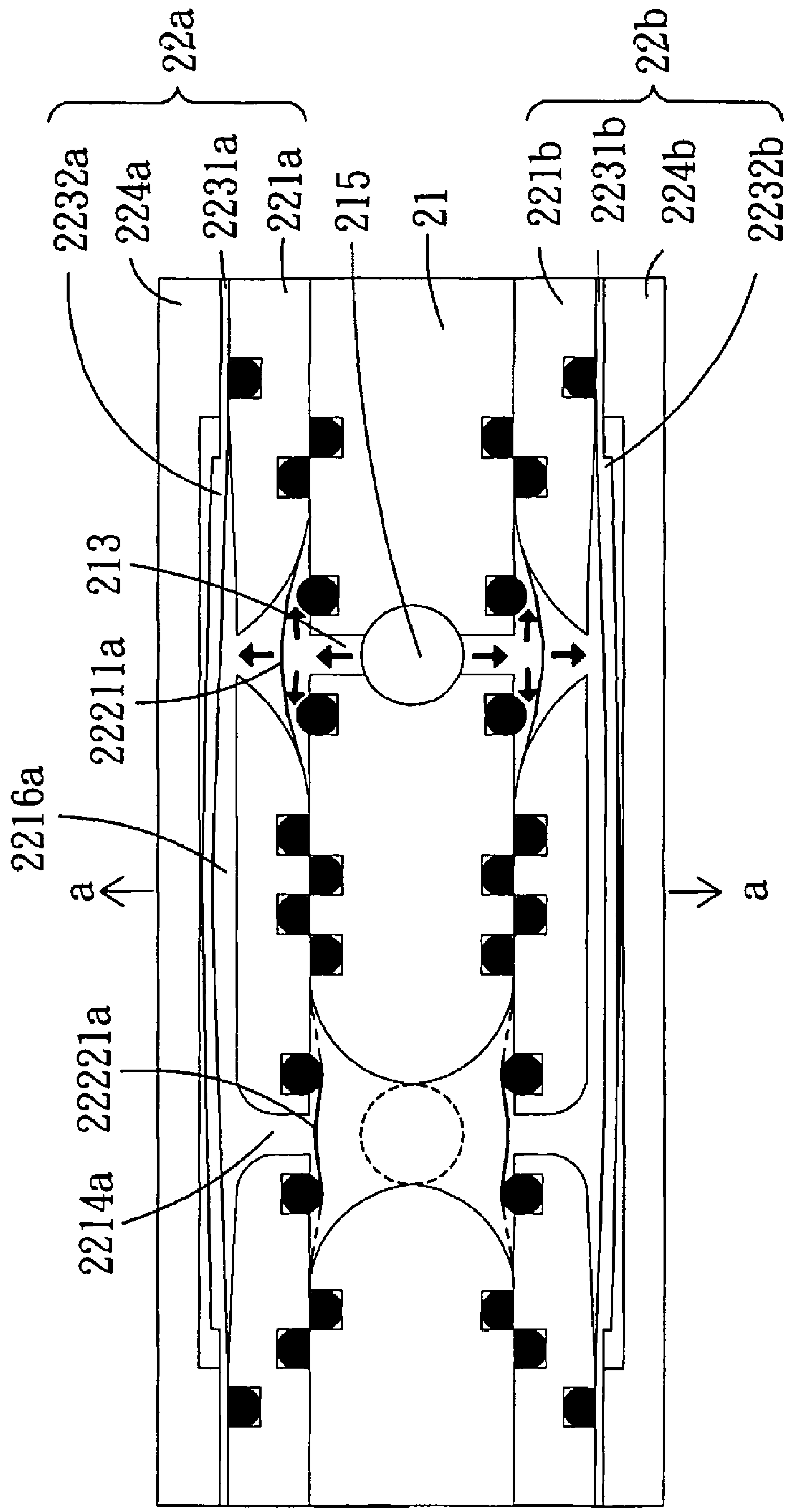
2221a
26
2213a
213
2215a
2216a
22122a
2222a
2214a
27
2141a
216
2215b
2213b
2216b
2214b

FIG. 6A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224b
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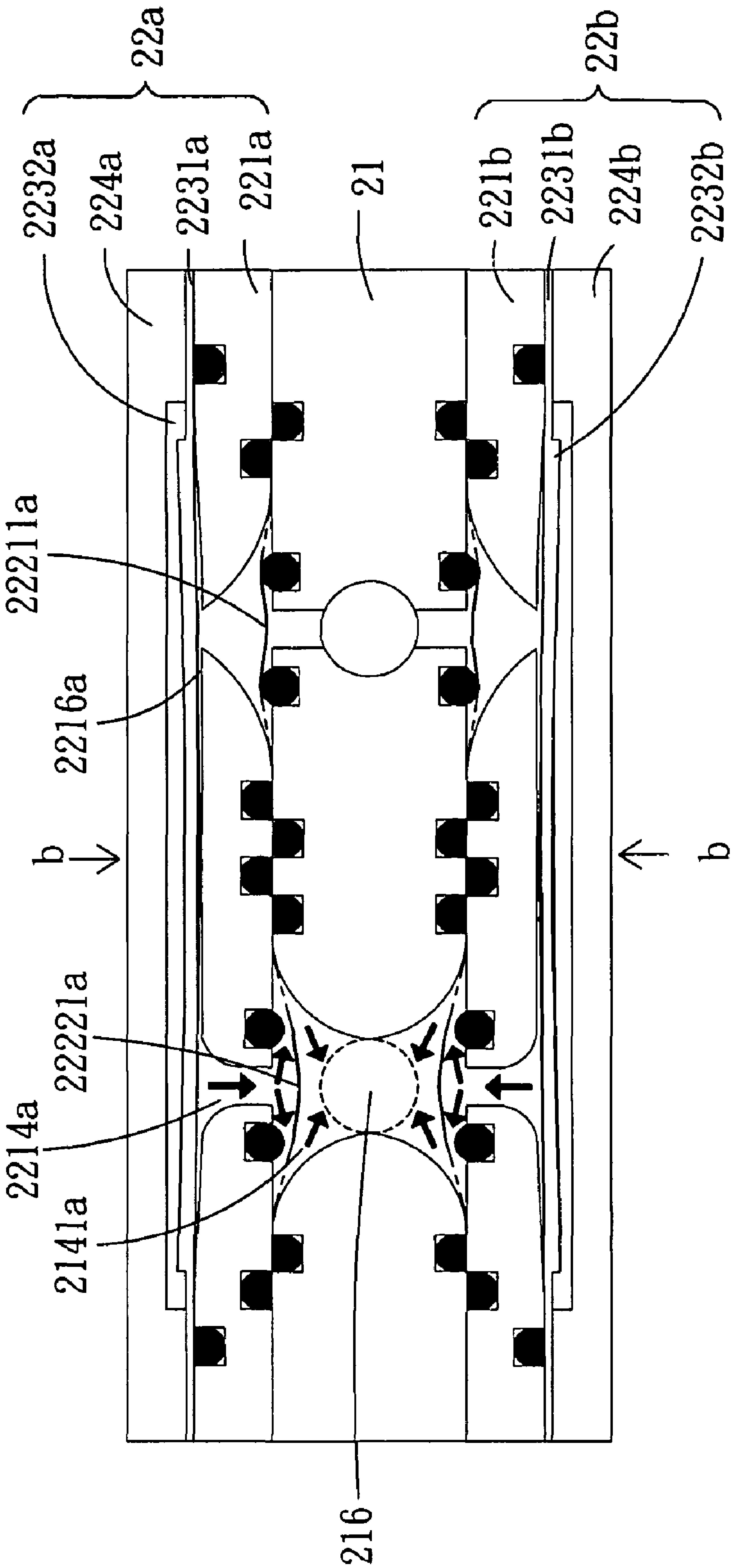
2216a
a
a
22221a
2214a

FIG. 6B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2231a
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22211a
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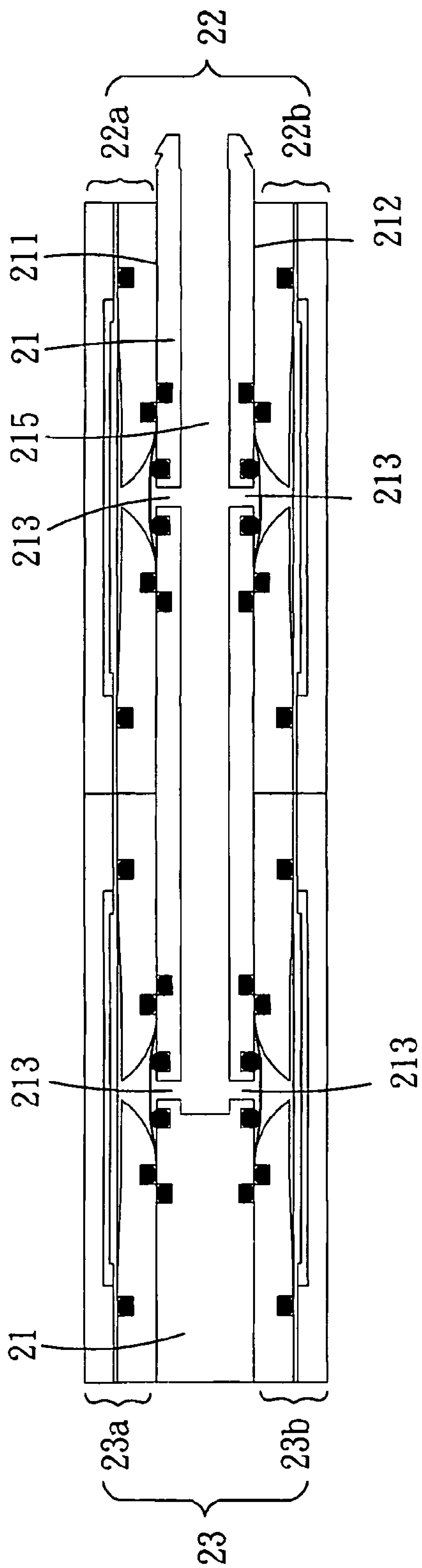
b
22221a
2214a
2141a
216

FIG. 6C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22a
22b
211
212
21
215
213
213
213
213
21
23a
23b
23

FIG. 7A

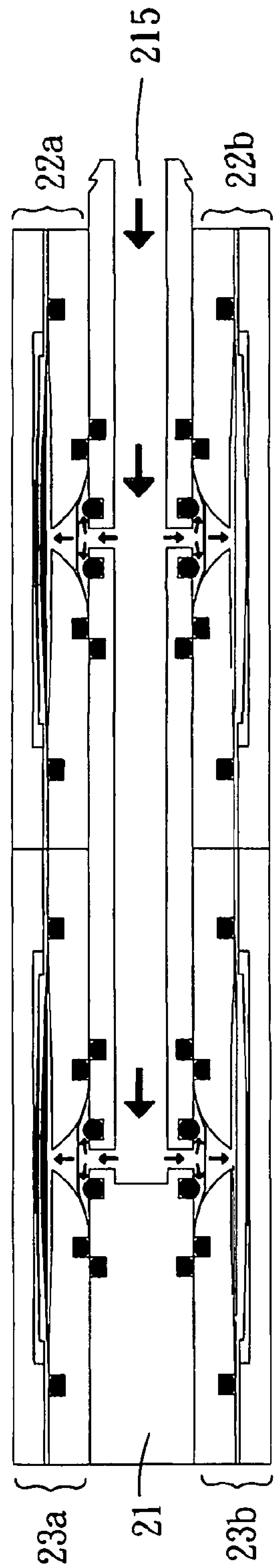

215
22a
22b
23a
21
23b

FIG. 7B

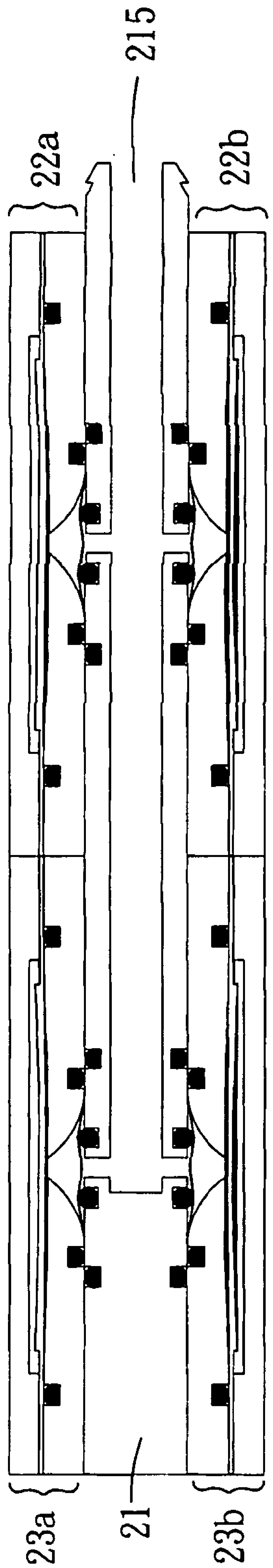
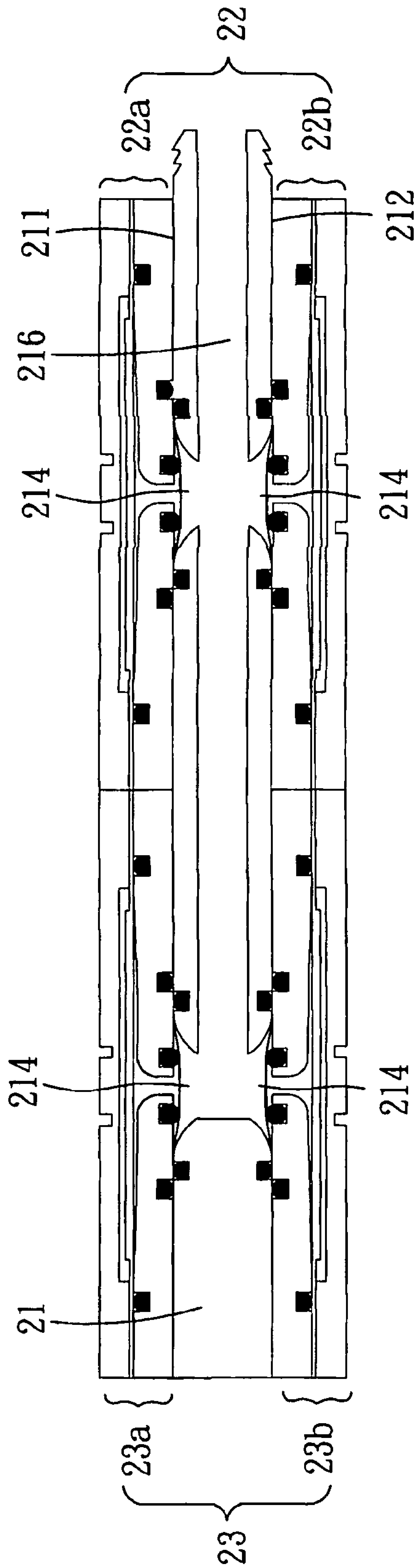

215
22a
22b
23a
21
23b

FIG. 7C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211
212
216
214
214
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214
21
23a
23b
23

FIG. 8A

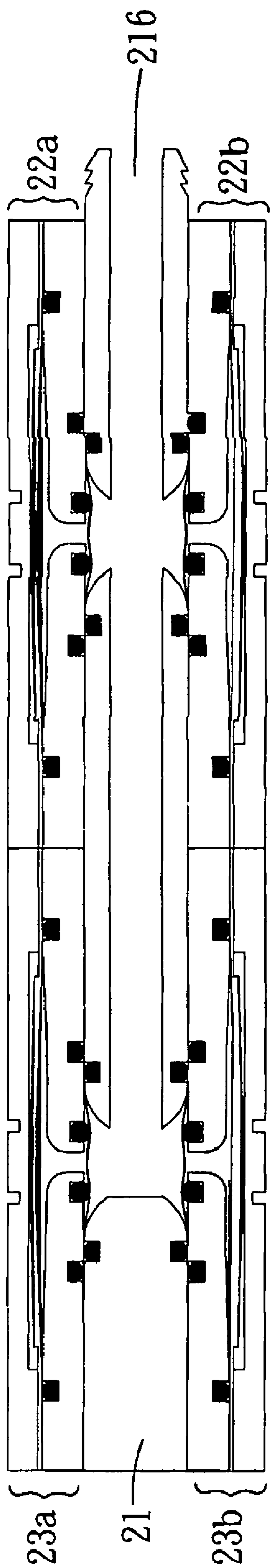

FIG. 8B

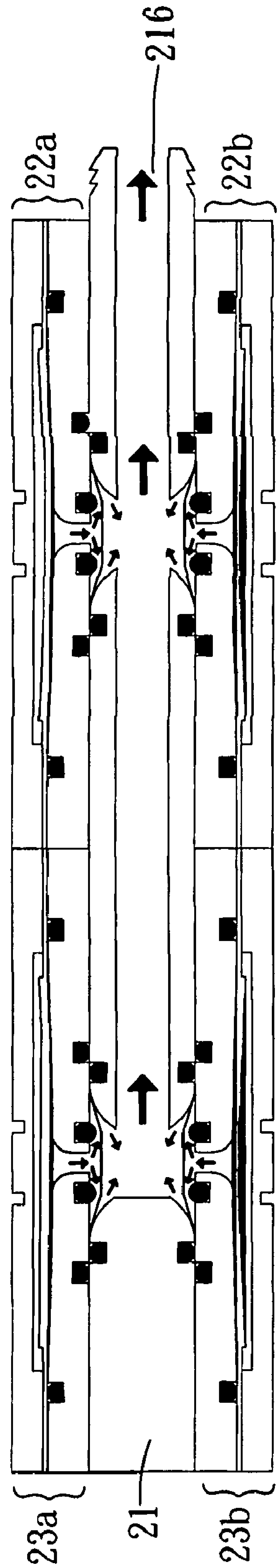

FIG. 8C

FLUID TRANSPORTATION DEVICE HAVING MULTIPLE DOUBLE-CHAMBER ACTUATING STRUCTURES

FIELD OF THE INVENTION

The present invention relates to a fluid transportation device, and more particularly to a fluid transportation device having multiple double-chamber actuating structures.

BACKGROUND OF THE INVENTION

Nowadays, fluid transportation devices used in many sectors such as pharmaceutical industries, computer techniques, printing industries, energy industries are developed toward miniaturization. The fluid transportation devices used in for example micro pumps, micro atomizers, printheads or industrial printers are very important components. Consequently, it is critical to improve the fluid transportation devices.

FIG. **1** is a schematic view of a conventional micro pump. The conventional micro pump **10** principally comprises a valve seat **11**, a valve cap **12**, a valve membrane **13**, a micro actuator **14** and a cover plate **15**. The valve membrane **13** includes an inlet valve structure **131** and an outlet valve structure **132**. The valve seat **11** comprises an inlet channel **111** and an outlet channel **112**. A pressure cavity **123** is formed between the valve cap **12** and the micro actuator **14**. The valve membrane **13** is arranged between the valve seat **11** and the valve cap **12**.

When a voltage is applied on both electrodes of the micro actuator **14**, an electric field is generated. The electric field causes downward deformation of the micro actuator **14**. In a case that the micro actuator **14** is subject to upwardly deformation in the direction X, the volume of the pressure cavity **123** is expanded to result in a suction force. Due to the suction force, the inlet valve structure **131** of the valve membrane **13** is opened and thus the fluid is transported into the pressure cavity **123** through the inlet channel **111** of the valve seat **11**, the inlet valve structure **131** of the valve membrane **13** and the inlet valve channel **121** of the valve cap **12**. On the other hand, if the micro actuator **14** is subject to downward deformation in a direction opposite to the direction X, the volume of the pressure cavity **123** is shrunk to result in an impulse. The impulse is exerted on the inlet valve structure **131** and the outlet valve structure **132** of the valve membrane **13**, so that the outlet valve structure **132** is opened. When the outlet valve structure **132** is opened, the fluid is exhausted from the pressure cavity **123** to the outside of the micro pump **10** through the outlet valve channel **122** of the valve cap **12**, the outlet valve structure **132** of the valve membrane **13** and the outlet channel **112** of the valve seat **11**. Meanwhile, a fluid transporting cycle is completed.

Although the conventional micro pump **10** is effective for transporting a fluid, there are still some drawbacks. For example, the conventional micro pump **10** has a single actuator, a signal pressure cavity, a single flow path, a single inlet/outlet and a single pair of valve structures. For increasing the flow rate of the micro pump **10**, an additional coupling mechanism is required to connect multiple micro pump units, which are stacked. Since the use of the coupling mechanism is very costly and the overall volume of multiple micro pump units is very bulky, the final product fails to meet the miniaturization demand.

For increasing the flow rate and reducing the overall volume, there is a need of providing a fluid transportation device

having multiple double-chamber actuating structures so as to obviate the drawbacks encountered from the prior art.

SUMMARY OF THE INVENTION

As previously described, an additional coupling mechanism is required to connect multiple micro pump units and stack the micro pump units in order to increase the flow rate of the conventional micro pump. The use of the coupling mechanism is very costly and the overall volume of multiple micro pump units is very bulky, the final product fails to meet the miniaturization demand. For increasing the flow rate and reducing the overall volume, the present invention provides a fluid transportation device having multiple double-chamber actuating structures.

In accordance with an aspect of the present invention, there is provided a fluid transportation device having multiple double-chamber actuating structures for transporting a fluid. The fluid transportation device includes a flow-gathering module and multiple double-chamber actuating structures. The flow-gathering module includes two surfaces opposed to each other, multiple first flow paths and multiple second flow paths running through the two surfaces, an inlet channel arranged between the two surfaces and communicated with the multiple first flow paths, and an outlet channel arranged between the two surfaces and communicated with the multiple second flow paths. The multiple double-chamber actuating structures are arranged on the flow-gathering module side by side. Each double-chamber actuating structure includes a first chamber and a second chamber symmetrically arranged on the two surface of the flow-gathering module. Each of the first chamber and the second chamber includes a valve cap arranged over the flow-gathering module, a valve membrane arranged between the flow-gathering module and the valve cap, and an actuating member having a periphery fixed on the valve cap.

The above contents of the present invention will become more readily apparent to those ordinarily skilled in the art after reviewing the following detailed description and accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of a conventional micro pump;

FIG. **2** is a schematic exploded view illustrating a fluid transportation device having multiple double-chamber actuating structures according to an embodiment of the present invention;

FIG. **3**A is a schematic assembled view illustrating the fluid transportation device of FIG. **2**;

FIG. **3**B is a schematic cross-sectional view illustrating the flow-gathering module of the fluid transportation device shown in FIG. **3**A and taken along the line A-A or the line a-a;

FIG. **3**C is a schematic cross-sectional view illustrating the flow-gathering module of the fluid transportation device shown in FIG. **3**A and taken along the line C-C;

FIG. **3**D is a schematic cross-sectional view illustrating the flow-gathering module of the fluid transportation device shown in FIG. **3**A and taken along the line B-B;

FIG. **4**A is a schematic cross-sectional view illustrating the valve cap of the first chamber included in the first double-chamber actuating structure of the fluid transportation device shown in FIG. **3**A and taken along the line A-A;

FIG. **4**B is a schematic cross-sectional view illustrating the valve caps of the first chambers included in the first and second double-chamber actuating structures of the fluid transportation device shown in FIG. **3**A and taken along the line C-C;

FIG. **4**C is a schematic cross-sectional view illustrating the valve caps of the first chambers included in the first and second double-chamber actuating structures of the fluid transportation device shown in FIG. **3**A and taken along the line B-B;

FIG. **5** is a schematic cross-sectional view illustrating the valve membrane of the first chamber included in the first double-chamber actuating structure of the fluid transportation device shown in FIG. **2**;

FIG. **6**A is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **3**A and taken along the line A-A, wherein the fluid transportation device is in a non-actuation status;

FIG. **6**B is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **6**A, in which the volume of the pressure cavity is expanded;

FIG. **6**C is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **6**A, in which the volume of the pressure cavity is shrunken;

FIG. **7**A is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **3**A and taken along the line B-B;

FIG. **7**B is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **7**A, in which the volume of the pressure cavity is expanded;

FIG. **7**C is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **7**A, in which the volume of the pressure cavity is shrunken;

FIG. **8**A is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **3**A and taken along the line C-C;

FIG. **8**B is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **8**A, in which the volume of the pressure cavity is expanded; and

FIG. **8**C is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **8**A, in which the volume of the pressure cavity is shrunken.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention will now be described more specifically with reference to the following embodiments. It is to be noted that the following descriptions of preferred embodiments of this invention are presented herein for purpose of illustration and description only. It is not intended to be exhaustive or to be limited to the precise form disclosed.

The fluid transportation device of the present invention includes a flow-gathering module and multiple double-chamber actuating structures. The multiple double-chamber actuating structures are symmetrically stacked on the flow-gathering module. The fluid transportation device of the present invention is capable of increasing flow rate and head without largely increasing the overall volume thereof. That is, the fluid transportation device of the present invention is feasible to the applications requiring high flow rate and high head.

FIG. **2** is a schematic exploded view illustrating a fluid transportation device having multiple double-chamber actuating structures according to an embodiment of the present invention. The fluid transportation device **2** of the present invention comprises a flow-gathering module **21** and multiple double-chamber actuating structures. For clarification and brevity, only two double-chamber actuating structures are shown in the drawings. That is, the fluid transportation device **2** has a first double-chamber actuating structure **22** and a second double-chamber actuating structure **23**. The first double-chamber actuating structure **22** and the second double-chamber actuating structure **23** are substantially identical. The number of the double-chamber actuating structures included in the fluid transportation device **2** of the present invention may be varied according to the practical requirements.

Each double-chamber actuating structure of the fluid transportation device **2** has two chambers at the upper side and the lower side, respectively. The double-chamber actuating structures are arranged on the flow-gathering module **21** side by side. FIG. **3**A is a schematic assembled view illustrating the fluid transportation device of FIG. **2**. Please refer to FIG. **2** and FIG. **3**A. The first double-chamber actuating structure **22** includes a first chamber **22*a*** and a second chamber **22*b***, which are respectively arranged on the first surface **211** and the second surface **212** of the flow-gathering module **21**. The first chamber **22*a*** has a valve cap **221*a***, a valve membrane **222*a***, an actuating member **223*a*** and a cover plate **224*a***. The second chamber **22*b*** has a valve cap **221*b***, a valve membrane **222*b***, an actuating member **223*b*** and a cover plate **224*b***. The first chamber **22*a*** and the second chamber **22*b*** are mirror-symmetrical with respect to the flow-gathering module **21**.

The second double-chamber actuating structure **23** includes a first chamber **23*a*** and a second chamber **23*b***, which are respectively arranged on the first surface **211** and the second surface **212** of the flow-gathering module **21**. The first chamber **23*a*** has a valve cap **231*a***, a valve membrane **232*a***, an actuating member **233*a*** and a cover plate **234*a***. The second chamber **23*b*** has a valve cap **231*b***, a valve membrane **232*b***, an actuating member **233*b*** and a cover plate **234*b***. The first chamber **23*a*** and the second chamber **23*b*** are mirror-symmetrical with respect to the flow-gathering module **21**.

In this embodiment, the first double-chamber actuating structure **22** and the second double-chamber actuating structure **23** are arranged on the flow-gathering module **21** side by side. That is, the first chamber **22*a*** of the first double-chamber actuating structure **22** and the first chamber **23*a*** of the second double-chamber actuating structure **23** are arranged on the first surface **211** of the flow-gathering module **21** side by side. In addition, the second chamber **22*b*** of the first double-chamber actuating structure **22** and the second chamber **23*b*** of the second double-chamber actuating structure **23** are arranged on the second surface **212** of the flow-gathering module **21** side by side.

FIG. **3**B is a schematic cross-sectional view illustrating the flow-gathering module of the fluid transportation device shown in FIG. **3**A and taken along the line A-A or the line a-a. FIG. **3**C is a schematic cross-sectional view illustrating the flow-gathering module of the fluid transportation device shown in FIG. **3**A and taken along the line C-C. FIG. **3**D is a schematic cross-sectional view illustrating the flow-gathering module of the fluid transportation device shown in FIG. **3**A and taken along the line B-B. Please refer to FIG. **2**, FIG. **3**A, FIG. **3**B, FIG. **3**C, and FIG. **3**D. The flow-gathering module **21** is substantially rectangular bar having the first surface **211** and the second surface **212**, which are opposed to each other. The flow-gathering module **21** has multiple first flow paths, multiple second flow paths, an inlet channel **215** and an outlet channel **216**. As shown in FIGS. **3**B, **3**C and **3**D, the multiple first flow paths are multiple inlet branch flow paths **213** that vertically run through the first surface **211** and the second surface **212**. The multiple second flow paths are multiple outlet confluent flow paths **214** that vertically run through the first surface **211** and the second surface **212**. In other words, the openings of respective inlet branch flow paths **213** at the first surface **211** and the second surface **212** are coaxial. Similarly, the openings of respective outlet confluent flow paths **214** are coaxial. The inlet branch flow paths **213** and the outlet confluent flow paths **214** are independent from each other (see FIG. **3**). The first surface **211** and the second surface **212** are communicated with each other through the inlet branch flow paths **213** and the outlet confluent flow paths **214**.

Please refer to FIG. **3**C and FIG. **3**D again. The inlet channel **215** and the outlet channel **216** are pipelines between the first surface **211** and the second surface **212**. The external flow is introduced into the fluid transportation device **2** through the inlet channel **215**. The internal flow is ejected out of the fluid transportation device **2** through the outlet channel **216**. The inlet channel **215** is communicated with the inlet branch flow paths **213** (see FIG. **3**D). The outlet channel **216** is communicated with the outlet confluent flow paths **214** (see FIG. **3**C). After the fluid transportation device is assembled, the inlet branch flow paths **213** are communicated with the surrounding environment through the inlet channel **215**, and the outlet confluent flow paths **214** are communicated with the surrounding environment through the outlet channel **216**.

Please refer to FIG. **3**B and FIG. **3**C again. The outlet confluent flow paths **214** that are close to the first surface **211** are outwardly expanded, so that a second buffer zone (i.e. the outlet buffer cavity **2141***a*) is collectively defined by the valve membrane **222***a* and **232***a* that are on the first surface **211**. The outlet confluent flow paths **214** that are close to the second surface **212** are outwardly expanded, so that another outlet buffer cavity **2141***b* is collectively defined by the valve membrane **222***b* and **232***b*. As such, the fluid introduced into the first chambers **22***a*, **23***a* and the second chambers **22***b*, **23***b* can be temporarily stored in the outlet buffer cavities **2141***a* and **2141***b*, then smoothly flows into the outlet confluent flow paths **214**, and finally ejected out of the fluid transportation device **2** through the outlet channel **216**.

Moreover, several recess structures are formed in the first surface **211** and the second surface **212**. The recess structures **217***a*, **218***a*, **217***b* and **218***b* are arranged in the outer peripheries of the inlet branch flow paths **213** and annularly surround the inlet branch flow paths **213**. The recess structures **219***a* and **219***b* are arranged in the outer peripheries of the outlet confluent flow paths **214** and annularly surround the outlet confluent flow paths **214**. The recess structures **217***a*, **218***a*, **219***a*, **217***b*, **218***b* and **219***b* are used for accommodating corresponding sealing rings **26** (as shown in FIG. **6**A).

In this embodiment, the flow-gathering module **21** is made of thermoplastic material. The sealing rings **26** are circular rings made of chemical-resistant and soft material. For example, the sealing rings **26** are rubbery rings that are methanol-resistant or acetic acid-resistant but not limited to the materials listed above.

Please refer to FIG. **2** again. The valve membrane **222***a*, the valve cap **221***a*, the actuating member **223***a* and the cover plate **224***a* of the first chamber **22***a* of the first double-chamber actuating structure **22** are stacked on the first surface **211** of the flow-gathering module **21**. Likewise, the valve membrane **232***a*, the valve cap **231***a*, the actuating member **233***a* and the cover plate **234***a* of the first chamber **23***a* of the second double-chamber actuating structure **23** are stacked on the first surface **211** of the flow-gathering module **21**. The valve membrane **222***a* is arranged between the first surface **211** of the flow-gathering module **21** and the valve cap **221***a*, and aligned with the flow-gathering module **21** and the valve cap **221***a*. Likewise, the valve membrane **232***a* is arranged between the first surface **211** of the flow-gathering module **21** and the valve cap **231***a*, and aligned with the flow-gathering module **21** and the valve cap **231***a*. The actuating member **223***a* is disposed above the valve cap **221***a*, and comprises a vibration film **2231***a* and an actuator **2232***a*. Likewise, the actuating member **233***a* is disposed above the valve cap **231***a*, and comprises a vibration film **2331***a* and an actuator **2332***a*. When a voltage is applied on the actuating member **223***a* or **233***a*, the actuating member **223***a* or **233***a* is subject to vibration so as to actuate the fluid transportation device **2**. The cover plate **224***a* and **234***a* are respectively disposed over the actuating members **223***a* and **233***a* for sealing the first chambers **22***a* and **23***a*. After the valve membrane **222***a*, the valve cap **221***a*, the actuating member **223***a* and the cover plate **224***a* are sequentially stacked from bottom to top and fixed on the first surface **211** of the flow-gathering module **21** by a fastening element (not shown), the first chamber **22***a* of the first double-chamber actuating structure **22** is defined. Likewise, after the valve membrane **232***a*, the valve cap **231***a*, the actuating member **233***a* and the cover plate **234***a* of the first chamber **23***a* are sequentially stacked from bottom to top and fixed on the first surface **211** of the flow-gathering module **21** by a fastening element (not shown), the first chamber **23***a* of the second double-chamber actuating structure **23** is defined. As previously, the second chamber **22***b* of the first double-chamber actuating structure **22** is disposed on the second surface **212** of the flow-gathering module **21**, wherein the first chamber **22***a* and the second chamber **22***b* are mirror-symmetrical with respect to the flow-gathering module **21**. The second chamber **23***b* of the second double-chamber actuating structure **23** is disposed on the second surface **212** of the flow-gathering module **21**, wherein the first chamber **23***a* and the second chamber **23***b* are mirror-symmetrical with respect to the flow-gathering module **21** (see FIGS. **2** and **6**A). For clearly describing the fluid transportation device **2**, only the first chamber **22***a* of the first double-chamber actuating structure **22** is illustrated in more details as follows.

FIG. **4**A is a schematic cross-sectional view illustrating the valve cap of the first chamber included in the first double-chamber actuating structure of the fluid transportation device shown in FIG. **3**A and taken along the line A-A. FIG. **4**B is a schematic cross-sectional view illustrating the valve caps of the first chambers included in the first and second double-chamber actuating structures of the fluid transportation device shown in FIG. **3**A and taken along the line C-C. FIG. **4**C is a schematic cross-sectional view illustrating the valve caps of the first chambers included in the first and second double-chamber actuating structures of the fluid transportation device shown in FIG. **3**A and taken along the line B-B. Please refer to FIGS. **4**A, **4**B, **4**C, **2** and **3**A. As shown in FIG. **2**, the valve cap **221***a* of the first chamber **22***a* of the first double-chamber actuating structure **22** is disposed on the first surface **211** of the flow-gathering module **21**. The valve cap **221***a* has an upper surface **2211***a* and a lower surface **2212***a*. The lower surface **2212***a* faces the first surface **211** of the flow-gathering module **21**. The valve membrane **222***a* is sandwiched between the lower surface **2212***a* of the valve cap **221***a* and the first surface **211** of the flow-gathering module **21**. The valve cap **221***a* further comprises a first valve channel and a second valve channel that run through the upper surface **2211***a* and the lower surface **2212***a*. In this embodiment, the first valve channel is an inlet valve channel **2213***a*, and the second valve channel is an outlet valve channel **2214***a* (see FIGS. **2** and **4**B). The inlet valve channel **2213***a* is aligned with an inlet branch flow path **213**. The outlet valve channel **2214***a* is aligned with the outlet buffer cavity **2141***a* (see FIGS. **2** and **6**). The inlet valve channel **2213***a* of the valve cap **221***a* that is close to the lower surface **2212***a* is outwardly expanded, so that a first buffer zone is collectively defined by the valve cap **221***a* and the valve membrane **222***a*. In this embodiment, the first buffer zone is an inlet buffer cavity **2215***a*, which is concavely formed in the lower surface **2212***a* of the valve cap **221***a* and corresponding to the inlet valve channel **2213***a*. The inlet buffer cavity **2215***a* is communicated with the inlet valve channel **2213***a* (see FIGS. **6**A and **4**C).

Please refer to FIGS. **2** and **6**A again. The upper surface **2211***a* of the valve cap **221***a* is partially depressed, so that a pressure cavity **2216***a* is collectively defined by the concave portion of the upper surface **2211***a* and the actuating member **223***a*. The pressure cavity **2216***a* is communicated with the inlet buffer cavity **2215***a* through the inlet valve channel **2213***a* (see FIG. **4**C). The pressure cavity **2216***a* is also communicated with the outlet buffer cavity **2141***a* (see FIG. **4**B). Moreover, several recess structures are formed in the valve cap **221***a*. The recess structures **22121***a*, **22122***a* and **22123***a* are formed in the lower surface **2212***a* of the valve cap **221***a*. The recess structure **22121***a* annularly surrounds the inlet valve channel **2213***a*. The recess structures **22122***a* and **22123***a* annularly surround the outlet buffer cavity **2141***a*. The recess structure **22111***a* is formed in the upper surface **2211***a* of the valve cap **221***a*. The recess structure **22111***a* annularly surrounds the pressure cavity **2216***a*. The recess structures **22121***a*, **22122***a*, **22123***a* and **22111***a* are used for accommodating corresponding sealing rings **27** (see FIG. **6**A). In this embodiment, the valve cap **221***a* is made of thermoplastic material. In addition, the valve cap **221***a* and the flow-gathering module **21** are made of the same material. The sealing rings **27** and the sealing rings **26** are made of the same material, and are not redundantly described herein.

FIG. **5** is a schematic cross-sectional view illustrating the valve membrane of the first chamber included in the first double-chamber actuating structure of the fluid transportation device shown in FIG. **2**. Please refer to FIGS. **2**, **5** and **6**A. The valve membrane **222***a* is produced by a conventional machining process, a photolithography and etching process, a laser machining process, an electroforming process or an electric discharge machining process. The valve membrane **222***a* is a sheet-like membrane with substantially uniform thickness and comprises several hollow-types valve switches (e.g. first and second valve switches). In this embodiment, the first valve switch is an inlet valve structure **2221***a* and the second valve switch is an outlet valve structure **2222***a*. The inlet valve structure **2221***a* is aligned with the inlet branch flow path **213** of the flow-gathering module **21**, the inlet valve channel **2213***a* of the valve cap **221***a* and the inlet buffer cavity **2215***a*. The outlet valve structure **2222***a* is aligned with the outlet confluent flow path **214** of the flow-gathering module **21**, the outlet buffer cavity **2141***a* and the outlet valve channel **2214***a* of the valve cap **221***a* (see FIG. **6**A).

Please refer to FIG. **5**. The inlet valve structure **2221***a* includes an inlet valve slice **22211***a* and several perforations **22212***a* formed in the periphery of the inlet valve slice **22211***a*. In addition, the inlet valve structure **2221***a* has several extension parts **22213***a* between the inlet valve slice **22211***a* and the perforations **22212***a*. Similarly, the outlet valve structure **2222***a* comprises an outlet valve slice **22221***a*, several perforations **22222***a* and several extension parts **22223***a*. The configurations and the operation principles of the outlet valve slice **22221***a*, the perforations **22222***a* and the extension parts **22223***a* included in the outlet valve structure **2222***a* are similar to corresponding components of the inlet valve structure **2221***a*, and are not redundantly described herein. In this embodiment, the valve membrane **222***a* is a flexible sheet-like membrane with substantially uniform thickness. The valve membrane **222***a* is made of excellent chemical-resistant organic polymeric material or metallic material, which includes but is not limited to polyimide (PI), aluminum, nickel, stainless steal, copper, copper alloy or nickel alloy.

As previously described, the valve membrane **222***a* is a flexible sheet-like membrane, and the valve membrane **222***a* is arranged between the first surface **21** of the flow-gathering module **21** and the valve cap **221***a*. If the volume of the pressure cavity **2216***a* is expanded to result in suction, the suction will cause the inlet valve structure **2221***a* and the outlet valve structure **2222***a* to shift toward the pressure cavity **2216***a*. Since the inlet valve channel **2213***a* and the outlet valve channel **2214***a* have distinguishable structure at the lower surface **2212***a* of the valve cap **221***a* (see FIGS. **4**A and **6**A), a negative pressure difference in the pressure cavity **2216***a* only causes the inlet valve structure **2221***a* of the valve membrane **222***a* to shift toward the valve cap **221***a* (see FIGS. **6**B and **7**B). At this moment, the outlet valve structure **2222***a* is attached on the lower surface **2212***a* of the valve cap **221***a* (see FIGS. **6**B and **8**B), and thus the fluid can only be transported from the flow-gathering module **21** to the valve cap **221***a* through the perforations **22212***a* of inlet valve structure **2221***a* (along the direction indicated as an arrow, see FIGS. **6**B and **7**B), and then transmitted to the pressure cavity **2216***a* through the inlet buffer cavity **2215***a* and the inlet valve channel **2213***a*. Under this circumstance, the outlet valve structure **2222***a* is closed, so that the fluid is not returned back.

Similarly, since the inlet branch flow paths **213** and the outlet confluent flow paths **214** have distinguishable structure at the first surface **211** of the flow-gathering module **21** (see FIGS. **2** and **3**B), a positive pressure difference in the pressure cavity **2216***a* causes downward force of the valve membrane **222***a*. In response to the downward force of the valve membrane **222***a*, the outlet valve structure **2222***a* is shifted toward the flow-gathering module **21**. At this moment, the inlet valve structure **2221***a* is attached on the first surface **211** of the flow-gathering module **21** to seal the inlet branch flow paths **213** of the flow-gathering module **21**, and thus the inlet valve structure **2221***a* is closed (see FIGS. **6**C and **7**C). In other words, the fluid can only be transported from the pressure cavity **2216***a* to the outlet valve channel **2214***a* of the flow-gathering module **21** through the perforations **22222***a* of the outlet valve structure **2222***a* (see FIGS. **6**C and **8**C). Under this circumstance, the inlet valve structure **2221***a* is quickly opened or closed in response to the positive or negative pressure difference in the pressure cavity **2216***a*, so that the outlet valve structure **2222***a* is correspondingly opened or closed to control transportation of the fluid and preventing the fluid from being returned back.

Please refer to FIG. **2** again. In the first chamber **22***a* of the first double-chamber actuating structure **22**, the actuating member **223***a* includes a vibration film **2231***a* and an actuator **2232***a*. The actuating member **223***a* has a periphery fixed on the valve cap **221***a*, so that the pressure cavity **2216***a* is collectively defined by the valve cap **221***a* and the actuating member **223***a* (see FIG. **6**A). The vibration film **221***a* of the actuating member **223***a* is a single-layered metallic structure. For example, the vibration film **2231***a* is made of stainless steel or copper, but not limited to the materials listed above. In some embodiments, the vibration film **2231***a* is a two-layered structure, which includes a metallic layer and a biochemical-resistant polymeric sheet attached on the metallic layer. The actuator **2232***a* is attached on the vibration film **2231***a*. The actuator **2232***a* is a piezoelectric plate made of highly piezoelectric material such as lead zirconate titanate (PZT). The cover plate **224***a* is disposed on the actuator **2232***a*. The valve membrane **222***a*, the valve cap **221***a* and the actuating member **223***a* are clamped between the cover plate **224***a* and the first surface **211** of the flow-gathering module **21**, thereby assembling the first chamber **22***a* of the first double-chamber actuating structure **22** of the fluid transportation device **2** as shown in FIG. **3**A.

Please refer to FIGS. **2**, **3**A and **6**A. FIG. **6**A is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **3**A and taken along the line A-A, wherein the fluid transportation device is in a non-actuation status. The cross-sectional view and the operations of the fluid transportation device taken along the line a-a are similar to those shown in FIG. **6**A, and are not redundantly described herein. For brevity, only the fluid transportation device taken along the line A-A is illustrated as follows. After the first chamber **22***a* of the first double-chamber actuating structure **22** is mounted on the first surface **211** of the flow-gathering module **21**, the inlet branch flow path **213** of the flow-gathering module **21** is aligned with the inlet valve structure **2221***a* of the valve membrane **222***a* and the inlet buffer cavity **2215***a* and the inlet valve channel **2213***a* of the valve cap **221***a*. At the same time, the outlet confluent flow path **214** of the flow-gathering module **21** is aligned with the outlet buffer cavity **2141***a*, the outlet valve structure **2222***a* of the valve membrane **222***a* and the outlet valve channel **2214***a* of the valve cap **221***a*.

As previously described, the recess structure **217***a* is formed in the first surface **211** of the flow-gathering module **21** and annularly surrounds the inlet branch flow path **213**. Since the thickness of the sealing ring **26** accommodated in the recess structure **217***a* is greater than the depth of the recess structure **217***a*, the sealing ring **26** is partially protruded out of the recess structure **217***a* to form a convex structure. Under this circumstance, the inlet valve slice **22211***a* of the inlet valve structure **2221***a* of the valve membrane **222***a* is raised. The convex structure is sustained against the valve membrane **222***a* to provide a pre-force on the inlet valve structure **2221***a*. The pre-force results in a stronger sealing effect to prevent the fluid from being returned back. In addition, due to the convex structure, a gap is formed between the inlet valve structure **22211***a* and the first surface **211** of the flow-gathering module **21**. The gap is helpful for opening the inlet valve structure **2221***a* during the fluid enters the gap. Similarly, after the sealing ring **27** is accommodated in the recess structure **22122***a* that is formed in the lower surface **2212***a* of the valve cap **221***a* and annularly surrounds the outlet buffer cavity **2141***a*, the sealing ring **27** is partially protruded out of the recess structure **22122***a* to form a convex structure. As such, the outlet valve structure **2222***a* of the valve membrane **222***a* is downwardly raised with respect to the valve cap **221***a*, and a gap is formed between the outlet valve slice **22221***a* and the lower surface **2212***a* of the valve cap **221***a*. The convex structures of the outlet valve structure **2222***a* and the inlet valve structure **2221***a* are arranged on opposite sides of the valve membrane **222***a*. The functions of the convex structure of the outlet valve structure **2222***a* are similar to that of the inlet valve structure **2221***a*, and are not redundantly described herein. As mentioned above, the convex structures are defined by the recess structures (**217***a*, **22122***a*) and corresponding sealing rings (**26**, **27**). Alternatively, the convex structures may be directly formed on the flow-gathering module **21** and the valve cap **221***a* by a semiconducting fabricating method such as a photolithography and etching process, an electroplating process or an electroforming process. Alternatively, the convex structures may be integrally formed with the flow-gathering module **21** and the valve cap **221***a* by ejecting thermoplastic material. The remainder of the valve membrane **222***a* is attached between the valve cap **221***a* and the flow-gathering module **21**. The sealing rings **26** and **27** received in the recess structures **218***a*, **219***a*, **22121***a*, **22123***a* and **22111***a* may facilitate close contact between the valve membrane **222***a*, the valve cap **221***a* and the flow-gathering module **21**, thereby avoiding fluid leakage.

Please refer to FIG. **6**A again. The valve cap **221***b*, the valve membrane **222***b*, the actuating member **223***b* and the cover plate **224***b* of the second chamber **22***b* of the first double-chamber actuating structure **22** are disposed on the second surface **212** of the flow-gathering module **21**. The first chamber **22***a* and the second chamber **22***b* are mirror-symmetrical with respect to the flow-gathering module **21**. The configurations and functions of the second chamber **22***b* are identical to those of the first chamber **22***a*. The configurations and functions of the first chamber **23***a* and the second chamber **23***b* of the second double-chamber actuating structure **23** are identical to those of the first chamber **22***a* and the second chamber **22***b* of the first double-chamber actuating structure **22**. For brevity, the fluid transportation process is illustrated by referring to the first chamber **22***a* of the first double-chamber actuating structure **22**. It is of course that the second chamber **22***b* and the first chamber **22***a* of the first double-chamber actuating structure **22** and the second chamber **23***b* and the first chamber **23***a* of the second double-chamber actuating structure **23** are synchronously actuated to transport the fluid.

FIG. **6**B is a schematic cross-sectional view illustrating the fluid transportation device of the present invention, in which the volume of the pressure cavity shown in FIG. **6**A is expanded. Take the first chamber **22***a* for example. When a voltage is applied on the actuator **2232***a*, the actuating member **223***a* is deformed in the direction "a" and thus the volume of the pressure cavity **2216***a* is expanded to result in a negative pressure difference and a suction. Due to the negative pressure difference and the suction, the inlet valve structure **2221***a* and the outlet valve structure **2222***a* of the valve membrane **222***a* are uplifted. Since the inlet valve structure is aligned with the inlet buffer cavity **2215***a*, the inlet valve slice **22211***a* is quickly opened in response to the pre-force provided by the recess structure **217***a* and the sealing ring **26** (see FIGS. **6**B and **7**B). As such, a great amount of fluid is introduced into the inlet channel **215** of the flow-gathering module **21** and then branched by the inlet branch flow paths **213**. As such, the fluid is transported into the first chamber **22***a*, and then transported to the pressure cavity **2216***a* through the perforations **22212***a* of the inlet valve structure **2221***a* of the valve membrane **222***a* and the inlet buffer cavity **2215***a* and inlet valve channel **2213***a* of the valve cap **221***a*. At this moment, the pulling force exerted on the outlet valve structure **2222***a* of the valve membrane **222***a* and the pulling force exerted on the inlet valve structure **2221***a* are in the same direction. In addition, the outlet valve structure **2222***a* close to the lower surface **2212***a* of the valve cap **221***a* and the inlet valve structure **2221***a* close to the lower surface **2212***a* of the valve cap **221***a* have different structures. The sealing ring **27** accommodated in the recess structure **22122***a* provides a pre-sealing effect. The pulling force exerted on the outlet valve structure **2222***a* of the valve membrane **222***a* causes the outlet valve slice **22221***a* to seal the outlet valve channel **2214***a*, and thus the fluid will not be returned back (see FIGS. **6**B and **8**B).

In a case that the direction of the electric field applied on the actuator **2232***a* is changed such that the actuator **242** is subject to deformation in the direction "b" (see FIG. **6**C), the actuating member **223***a* is deformed toward the flow-gathering module **21** to compress the pressure cavity **2216***a*. As such, the volume of the pressure cavity **2216***a* is shrunk to result in a positive pressure difference from the surrounding environment. In response to the positive pressure difference, an impulse is applied on the fluid within the pressure cavity **2216***a*. Due to the impulse, a great amount of fluid is instantly exhausted out of the pressure cavity **2216***a* through the outlet valve channel **2214***a*. At the same time, the impulse generated from the positive pressure difference of the pressure cavity **2216***a* and in the direction toward the flow-gathering module **21** is also exerted on the inlet valve structure **2221***a* and the outlet valve structure **2222***a* of the valve membrane **222***a*. As such, a pre-force will quickly open the outlet valve slice **22221***a* of the outlet valve structure **2222***a*. When the outlet valve slice **22221***a* is opened, the fluid in the pressure cavity **2216***a* is transported to the outlet buffer cavity **2141***a* and the outlet confluent flow paths **214** through the outlet valve channel **2214***a* of the valve cap **221***a* and the perforations **22222***a* of the outlet valve structure **2222***a* of the valve membrane **222***a* (see FIGS. **6**C and **8**C), and then exhausted out of the fluid transportation device through the outlet channel **216**. Meanwhile, a fluid transporting cycle is completed.

On the other hand, the inlet branch flow path **213** close to the first surface **211** of the flow-gathering module **21** and the outlet confluent flow path **214** close to the first surface **211** of the flow-gathering module **21** have different structures. In addition, the sealing ring **26** provides a pre-sealing effect. As such, when the impulse in the direction toward the flow-gathering module **21** is exerted on the inlet valve structure **2221***a*, the inlet valve structure **2221***a* is pressed down to its closed position by the inlet valve slice **22211***a*, and thus the inlet branch flow path **213** is sealed (see FIGS. **6**C and **7**C). At this moment, no fluid is allowed to flow through the inlet valve structure **2221***a* and thus the fluid will not be returned back.

In a case that the actuator **2232***a* is subject to upward deformation due to a voltage applied thereon, the volume of the pressure cavity **2216***a* is expanded. As such, the fluid is transported from the inlet buffer cavity **2215***a* into the pressure cavity **2216***a* through the inlet valve channel **2213***a*. In a case that the actuating member **223***a* is subject to downward deformation, the volume of the pressure cavity **2216***a* is shrunk and thus the fluid is exhausted out of the pressure cavity **2216***a*. That is, by changing the direction of the electric field applied on the actuating member **223***a* is changed, the actuating member **223***a* is moved in a reciprocating manner, so that the fluid transportation device **2** is capable of pumping and releasing the fluid and achieving the purpose of transporting the fluid.

Please refer to FIGS. **7**A~**7**C and FIGS. **8**A~**8**C. FIG. **7**A is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **3**A and taken along the line B-B. FIG. **8**A is a schematic cross-sectional view illustrating the fluid transportation device shown in FIG. **3**A and taken along the line C-C. As shown in FIG. **7**A, the inlet channel **215** is a pipeline between the first surface **211** and the second surface **212** of the flow-gathering module **21**. The external flow is introduced into the fluid transportation device **2** through the inlet channel **215**. The inlet channel **215** is communicated with the multiple inlet branch flow paths **213**, so that the fluid is transported though the inlet branch flow paths **213** to the first chamber **22***a* and the second chamber **22***b* of the first double-chamber actuating structure **22** and the first chamber **23***a* and the second chamber **23***b* of the second double-chamber actuating structure **23**. As shown in FIG. **8**A, the outlet channel **216** is a pipeline between the first surface **211** and the second surface **212** of the flow-gathering module **21**. The internal flow is ejected out of the fluid transportation device **2** through the outlet channel **216**. The outlet channel **216** is communicated with the multiple outlet confluent flow paths **214**, so that the fluid from the first chamber **22***a* and the second chamber **22***b* of the first double-chamber actuating structure **22** and the first chamber **23***a* and the second chamber **23***b* of the second double-chamber actuating structure **23** is exhausted out of the fluid transportation device **2** through the outlet channel **216**.

Please refer to FIGS. **7**B and **8**B. As shown in FIG. **7**B, when the fluid is introduced into the inlet channel **215**, a portion of fluid is firstly transported to the first chamber **22***a* and the second chamber **22***b* of the first double-chamber actuating structure **22** through a first inlet branch flow path **213**, and then transported to the first chamber **23***a* and the second chamber **23***b* of the second double-chamber actuating structure **23** through a second inlet branch flow path **213**. If the fluid transportation device **2** has three or more double-chamber actuating structures, the rest may be deduced by analogy.

When the actuators includes in the first chamber **22***a* and the second chamber **22***b* of the first double-chamber actuating structure **22** and the first chamber **23***a* and the second chamber **23***b* of the second double-chamber actuating structure **23** are vibrated at the same frequency, all actuating members are externally raised. As such, all inlet valve structures are opened and the fluid is pumped into the chambers (see FIG **7**B). At the same time, all outlet valve structures are more tightly closed (see FIG. **8**B), and thus the fluid will not be returned back.

Please refer to FIGS. **7**C and **8**C. When the actuators includes in the first chamber **22***a* and the second chamber **22***b* of the first double-chamber actuating structure **22** and the first chamber **23***a* and the second chamber **23***b* of the second double-chamber actuating structure **23** are vibrated at the same frequency, all actuating members are internally concaved to compress the pressure cavity to result in a positive pressure difference. As such, all outlet valve structures are opened and the fluid to discharge the fluid (see FIG. **8**C). At the same time, all inlet valve structures are more tightly closed (see FIG. **7**C), and thus the fluid will not be returned back. The detail operations have been described in FIG. **6**, and are not redundantly described herein.

From the above description, the fluid transportation device of the present invention includes a flow-gathering module and multiple double-chamber actuating structures. The multiple double-chamber actuating structures are symmetrically stacked on the flow-gathering module. For assembling the fluid transportation device, two sets of valve membranes, valve caps and actuating members are respectively stacked on the first and second surfaces of the flow-gathering module, thereby forming a double-chamber actuating structure with two mirror-symmetrical chambers. Next, multiple double-chamber actuating structures are successively arranged on the fluid transportation device in a side-by-side manner. As a consequence, the double-chamber actuating structures are horizontally expanded. In comparison with the conventional micro pump with multiple single-chamber structures, the fluid transportation device of the present invention has increased flow rate and head. In addition, the fluid transportation device of the present invention has reduced overall volume, thereby meeting the miniaturization demand.

While the invention has been described in terms of what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention needs not be limited to the disclosed embodiment. On the contrary, it is intended to cover various modifications and similar arrangements included within the spirit and scope of the appended claims which are to be accorded with the broadest interpretation so as to encompass all such modifications and similar structures.

What is claimed is:

1. A fluid transportation device having multiple double-chamber actuating structures for transporting a fluid, said fluid transportation device comprising:

a flow-gathering module comprising two surfaces opposed to each other, multiple first flow paths and multiple second flow paths running through said two surfaces, an inlet channel arranged between said two surfaces and communicated with said multiple first flow paths, and an outlet channel arranged between said two surfaces and communicated with said multiple second flow paths; and

multiple double-chamber actuating structures arranged on said flow-gathering module side by side, wherein each double-chamber actuating structure includes a first chamber and a second chamber arranged symmetrically opposite one another on said two surfaces of said flow-gathering module, and each of said first chamber and said second chamber includes a valve cap arranged over said flow-gathering module and having a first valve channel and a second valve channel, a valve membrane arranged between said flow-gathering module and said valve cap, and an actuating member having a periphery fixed on said valve cap.

2. The fluid transportation device having multiple double-chamber actuating structures according to claim **1** wherein said valve membrane includes a first valve structure and a second valve structure corresponding to said first flow path and said second flow path, respectively.

3. The fluid transportation device having multiple double-chamber actuating structures according to claim **2** wherein a first buffer zone is arranged between said valve membrane and said valve cap, and a second buffer zone is arranged between said valve membrane and said flow-gathering module.

4. The fluid transportation device having multiple double-chamber actuating structures according to claim **3** wherein said first valve structures, said first buffer zones and said first valve channels of said first chamber and said second chamber are aligned with said first flow path of said flow-gathering module, and said second buffer zones, said second valve structures and said second valve channels of said first chamber and said second chamber are aligned with said second flow path of said flow-gathering module.

5. The fluid transportation device having multiple double-chamber actuating structures according to claim **1** wherein said actuating member and said valve cap collectively define a pressure cavity.

6. The fluid transportation device having multiple double-chamber actuating structures according to claim **1** wherein said fluid includes a gas and a liquid.

7. The fluid transportation device having multiple double-chamber actuating structures according to claim **1** wherein said actuating member includes an actuator and a vibration film.

8. The fluid transportation device having multiple double-chamber actuating structures according to claim **1** wherein said first flow paths are inlet branch flow paths, and said second flow paths are outlet confluent flow paths.

9. The fluid transportation device having multiple double-chamber actuating structures according to claim **1** wherein said actuating members included in said first chambers and said second chambers of said multiple double-chamber actuating structures are vibrated at the same frequency.

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